RELIABILITY BLOCK DIAGRAMS

(06)

RELIABILITY BLOCK DIAGRAMS

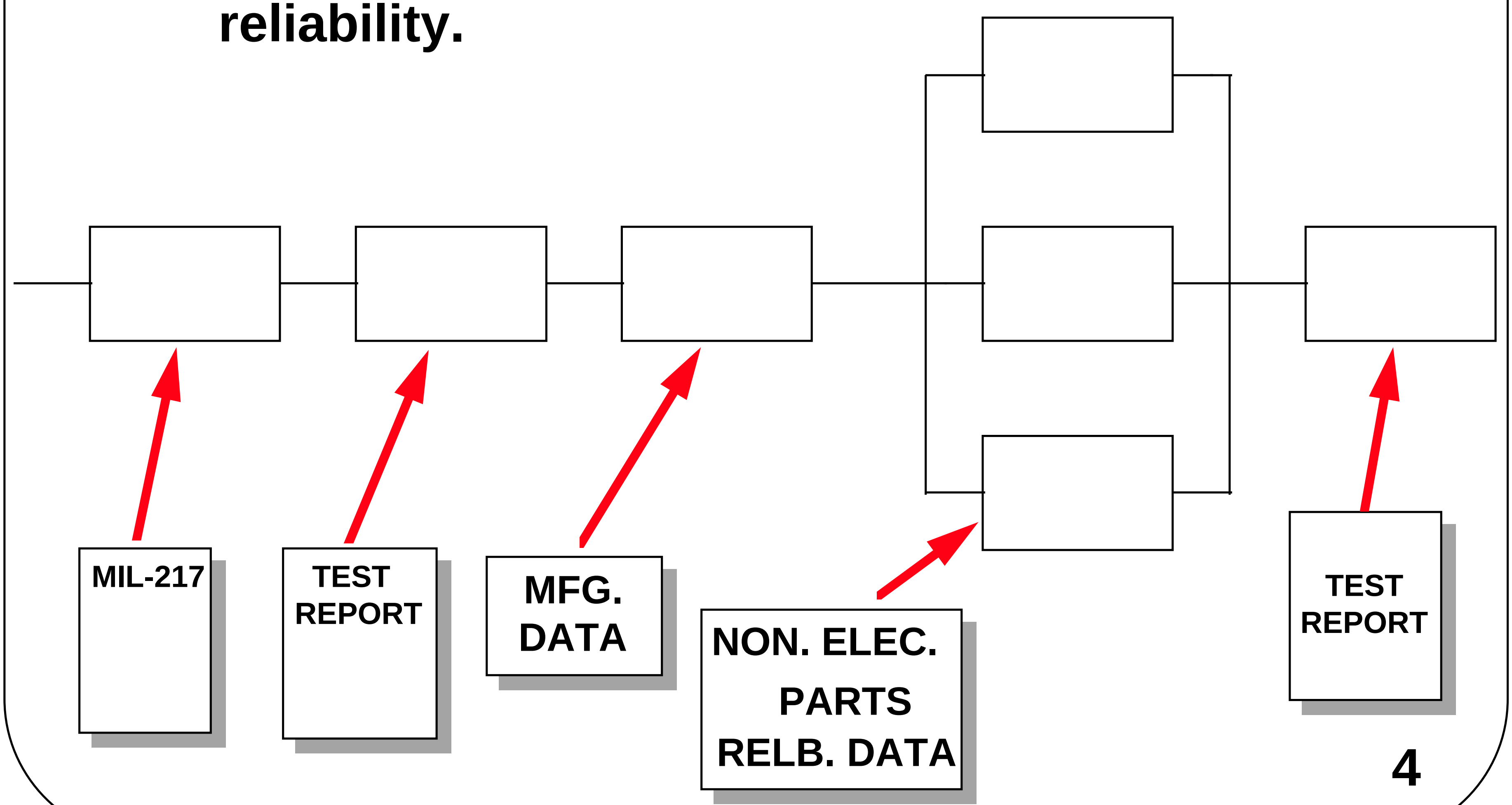
- A static form of reliability analysis using inter-connected boxes (blocks) to show and analyze the effects of failure of any component in the system. They also aid in evaluation of the overall reliability of the system.

PURPOSE of RELIABILITY BLOCK DIAGRAMS (RBDs)

- **RBDs SHOW THE FAILURE LOGIC OF THE SYSTEM WITH BLOCK DIAGRAMS.**
- **WHEN USED:**
- **They can be used for electro-mechanical systems to provide an overall assessment of how the system "handles" failures.**

RBDs COLLECT RELIABILITY DATA

- **RBDs are the usual collection point for component reliability data and are used to make the overall system assessment of reliability.**



OBJECTIVES:

- Be able to answer (or explain):
- How are reliability block diagrams (RBDs) generated?
- Be able to solve a simple series & simple parallel RBDs.
- Be able to solve complex RBDs and be able to solve RBDs with m out of n redundancy.
- Bathtub curve: What are the three regions of the curve? How are failures in each region generated? How can each be eliminated?

OUTLINE

- Data Requirements
- Simple Series RBDs.
- Simple Parallel RBDs
- Comparisons of Series & Parallel RBDs
- Complex System RBDs
  - COMBINATION OF SERIES AND PARALLEL SYSTEMS.
  - ACTIVE REDUNDANCY
  - STANDBY REDUNDANCY
  - m OUT OF n REDUNDANCY
- Additional Information

DATA REQUIREMENTS

- **THE RBD IS OFTEN GENERATED FROM A System Diagram.**
- **THE RBD MUST CORRESPOND TO THE DEFINITIONS OF WHAT CONSTITUTES A SYSTEM FAILURE. (RBDs may be different for different system definitions -- e.g. level of analysis, etc.).**
- **THE SOURCES OF EACH RELIABILITY NUMBER NEEDS TO BE KNOWN AND agreed to by the team (e.g. test data, MIL-HDBK-217, other sources).**

Simple Series RBDs

$$R_s = R_1 R_2 R_3 \ldots R_n = \prod_{i=1}^{n} R_i$$

- where
- R_s = probability that system will work.
- R_i = reliability of i^{th} part
- n = total number of parts

Example-Series Connected Device

- Example: A system has 100 parts, each one required for system success. Find the system reliability R_s if each part has R = 0.99.
- Solution:

$$R_s = R_1 R_2 R_3 \ldots R_n = \prod^{n}_{i=1} R_i$$

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- R_s =(0.99)(0.99)(0.99) . . . (0.99) = $(0.99)^{100}$
- R_s =0.366

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Problem--Series Redundancy

Calculate the following reliability for a 1000 hour mission. *R = exp (- λt)*.

Part 1	Part 2
$\lambda_1 = 120/10^6$	$\lambda_2 = 120/10^6$
$t_1 = 1000$	$t_2 = 1000$

$$R_{1000} = e^{-\lambda 1t1} = e^{-[(120/10\text{^}6)x10\text{^}3]} = e^{-.120} = 0.8869$$

$$R_{total} = R_{1000} \times R_{1000} = 0.8869 \times 0.8869 = 0.7866$$

Calculate the reliability for a 200 hour mission.

$$R_{200} = e^{-\lambda 1t1} = e^{-[(\_\_\_\_\_\_\_\_)x\_\_\_\_\_\_\_\_]} = e^{--}\ \_\_\_\_\_\_\_\_$$

$$R_{200} = \_\_\_\_\_\_\_\_$$

$$R_{total} = R_{200} \times R_{200} = \_\_\_\_\_\_\_\_ \times \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_$$

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Simple Parallel RBDs

Simple Redundancy Development

For 2 components in parallel

$$R_1R_2 + R_1Q_2 + Q_1R_2 + Q_1Q_2$$

where

$R_1\,R_2$ = both parts succeed

$R_1\,Q_2$ = part 1 succeeds and part 2 fails

$Q_1\,R_2$ = part 1 fails and part 2 succeeds

$Q_1\,Q_2$ = both parts fail

The sum of all possible events add to 1

$$R_1R_2 + R_1Q_2 + Q_1R_2 + Q_1Q_2 = 1$$

If one component must succeed for system success, then

$$R_1R_2 + R_1Q_2 + Q_1R_2 = 1 - Q_1Q_2$$

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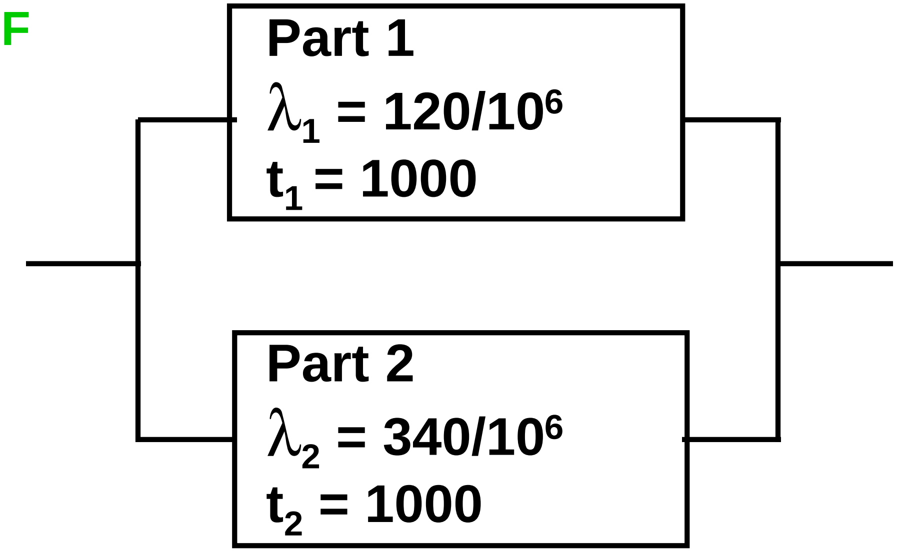
Simple Parallel RBDs - Example



- **Solve for the reliability of Parts 1 & 2.**
- $R_1 = e^{-\lambda 1t1} = e^{-[(120/10\text{^}6)x10\text{^}3]} = e^{-.120} = 0.887$
- $R_2 = e^{-\lambda 2t2} = e^{-[(\_\_\_\_\_\_\_\_)x\_\_\_\_]} = e^{-\_\_\_\_} = \_\_\_\_\_\_\_\_$
- **Solve for the unreliability of each part.**
- $Q_1 = 1 - R_1 = 0.1131$ $Q_2 = 1 - R_2 = \_\_\_\_\_\_\_\_\_$
- **Solve for the reliability of the redundant sys.**
- $R = 1\text{-}Q_1 Q_2 = 1\text{-} (\_\_\_\_\_) (\_\_\_\_\_) = 1 - \_\_\_\_\_\_ = \_\_\_\_\_\_$

General Equation for Redundancy

$$R_{\text{simple redundant}} = 1 - \prod_{j=1}^{n} Q_j = 1 - (Q_1 Q_2 Q_3 \ldots Q_n)$$

where

$\prod_{j=1}^{n} Q_j$ **=Total probability of failure**

Q_j **= total probability of failure of jth redundant path**

n **= total number of redundant paths**

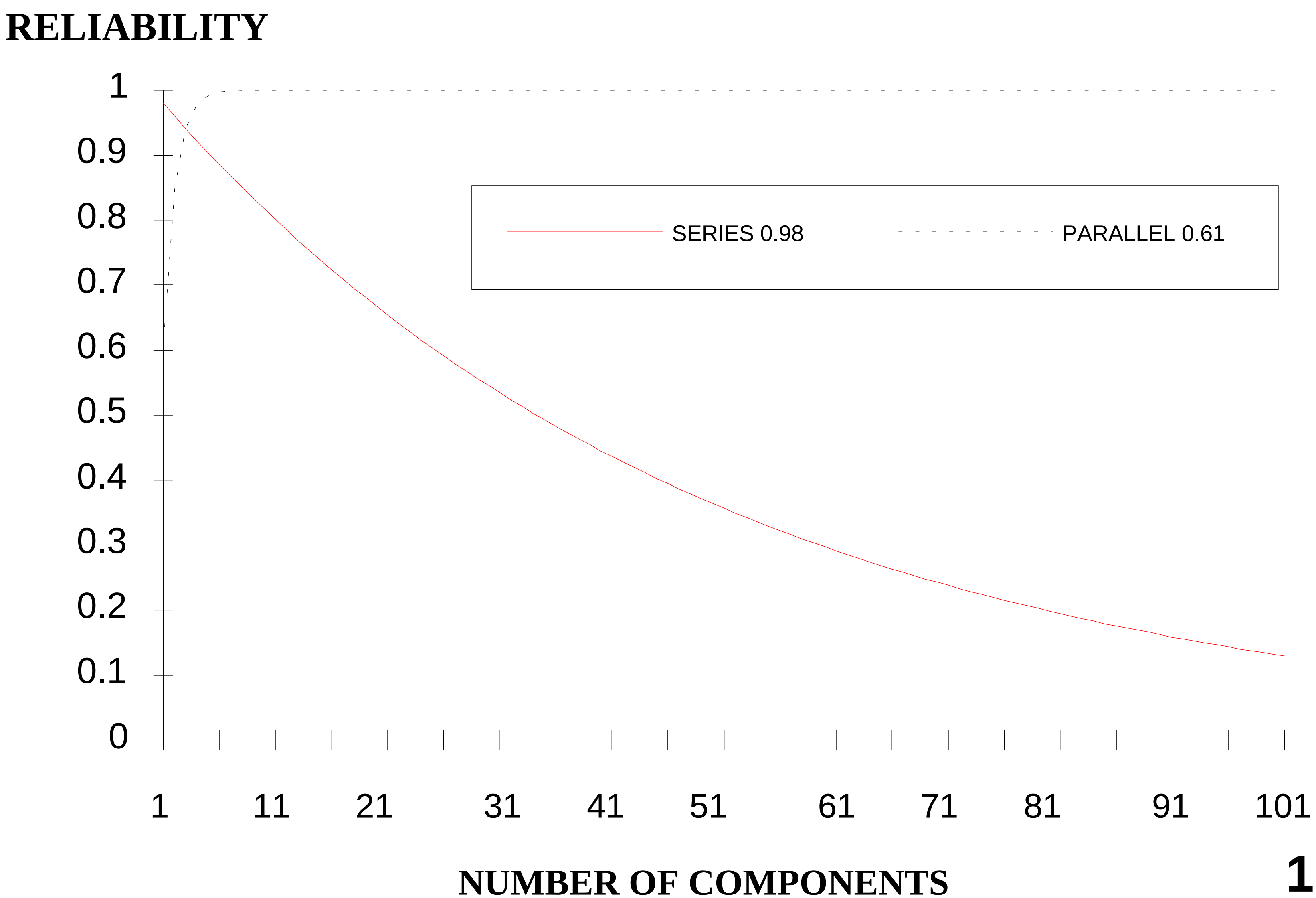
SERIES RELIABILITY

$$\boxed{0.98} \times \boxed{0.98} \times \boxed{0.98} = \boxed{0.94}$$

PARALLEL RELIABILITY

0.61		1 - 0.61		
		X		
0.61	1 -	1 - 0.61	=	0.94
		X		
0.61		1 - 0.61		

SERIES vs PARALLEL RELIABILITY



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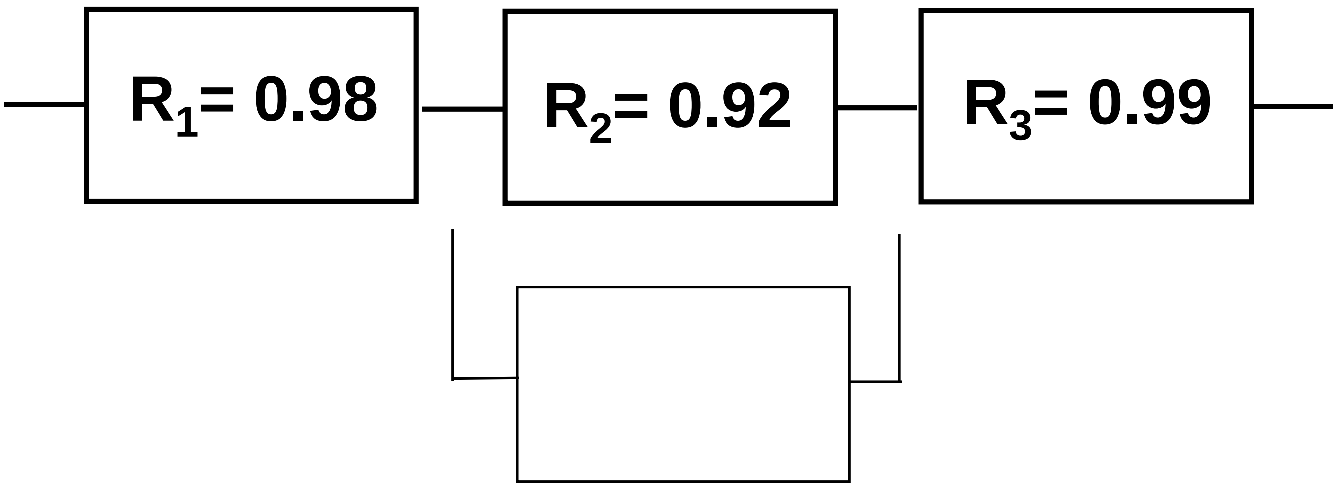
PROBLEM

- CALCULATE THE RELIABILITY FOR THE SYSTEM IN FIGURE 1.
- REPLACE R_2 WITH A PARALLEL UNIT AND RECALCULATE RELIABILITY.

Figure 1 -- System Diagram

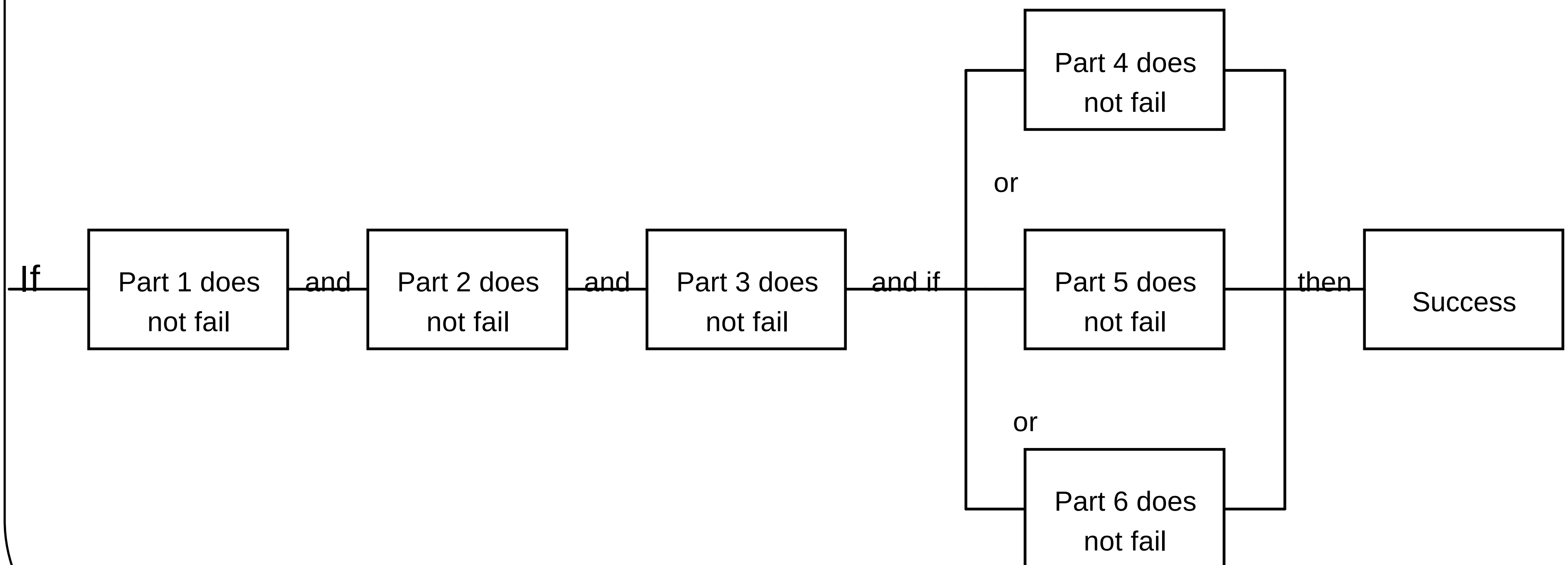


COMPLEX MODEL
Combination series and parallel

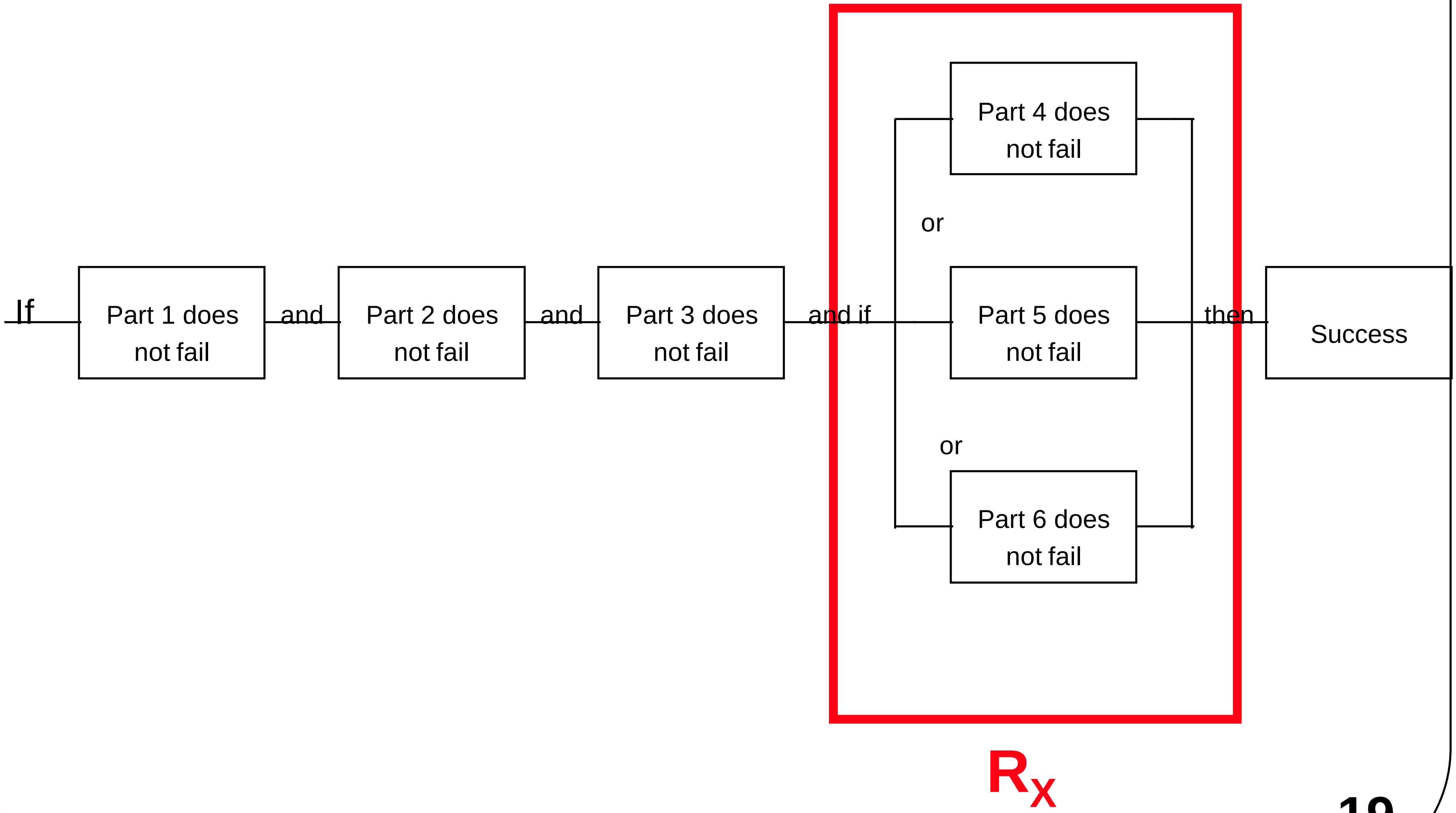
- **CALCULATING REDUNDANCY FOR A COMPLETE SYSTEM:**
- **Develop model.**
- **Write equation for the probability of success.**
- **ALTERNATIVELY--REDUCE SYSTEM TO SIMPLE SERIES OR PARALLEL SYSTEM.**
- **Use failure rates and operating times of elements.**
- **Calculate reliability of system.**

CALCULATE the RELIABILITY FOR the COMPLETE SYSTEM shown if Figure 2.

Figure 2 -- Block Diagram



EXAMPLE (con't)



EXAMPLE (con't)

- $R_1 = 0.99$, $R_2 = 0.999$, $R_3 = 0.95$
- $R_4 = 0.85$, $R_5 = 0.89$, $R_6 = 0.78$

Solving first for the parallel portion of the system we have:

- $R_X = 1 - Q_4 Q_5 Q_6 = 1 - (1-0.85)(1-0.89)(1-0.78)$
- $R_X = 1 - (0.15)(0.11)(0.22) = 1 - 0.00363 = 0.996$

Now solving the series diagram we have:

- $R_s = R_1 R_2 R_3 R_X$
- $R_s = (0.99)(0.999)(0.95)(0.996) = 0.936$

Problem: Add parallel redundancy to component # 3:

$R'_s = R_1 R_2 R'_3 R_X$

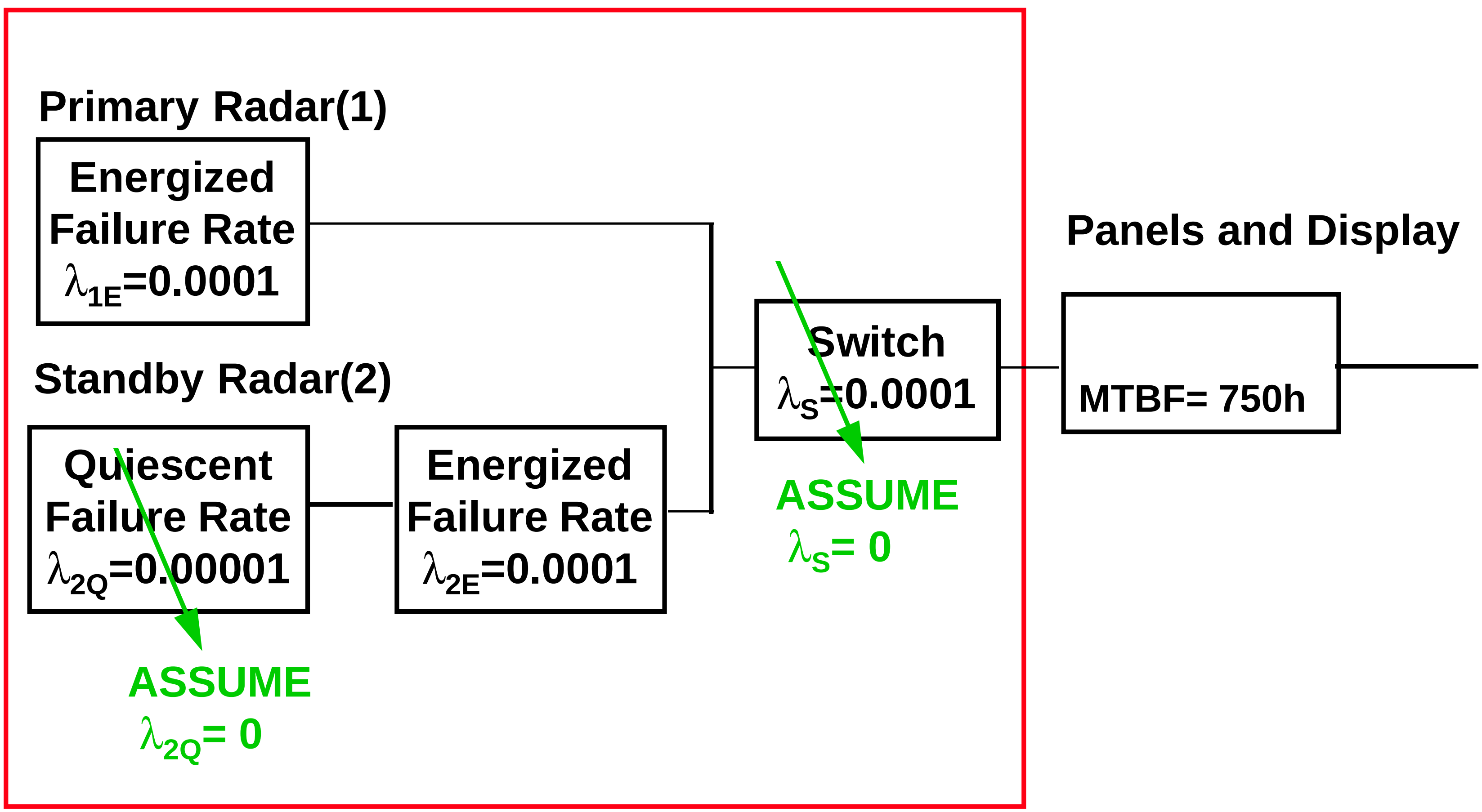
$R'_3 = 1 - Q_3 Q_3 = 1 - (\_\_\_\_\_\_\_\_)(\_\_\_\_\_\_\_\_) = \_\_\_\_\_\_\_\_$

$R'_s = (0.99) \times (0.999) \times (\_\_\_\_\_\_\_\_) \times (0.9964) = \_\_\_\_\_\_\_\_$

COMPLEX REDUNDANCY
Active & Standby Redundancy

- **Active Redundancy** assumes all systems are operating (e.g. all aircraft engines are running).
- **Standby Redundancy** is achieved when one unit does not operate continuously but is only switched on when the primary unit fails (e.g. a standby electrical generating system).
- The standby unit and the sensing and switching system may be considered to have a ‘one-shot reliability of starting and maintaining system function until the primary unit is repaired.

COMPLEX REDUNDANCY
Standby Redundancy



COMPLEX REDUNDANCY
Standby Redundancy

- Assume one shot switching reliability = 1 and quiescent failure rate of standby system = 0.
- System is non-maintained, equal constant failure rates, $\lambda_1 = \lambda_2 = 0.0001$ and t = 100hr.
- When $\lambda_1 = \lambda_2$ and $\lambda_{2Q} = 0$, the following equation may be used:

The general reliability formula for n equal units in a standby redundant configuration (with perfect switching, $R_S = 1$) is:

$$R = \sum_{i=0}^{n-1} \{(\lambda t)^i / i!\} e^{(-\lambda t)}$$

COMPLEX REDUNDANCY
Standby Redundancy (con't)

- **SUBSTITUTING λ =.0001 and t = 1000 into the above equation and solving for only the switchable portion of the system we have:**

$$R = ((\lambda t)^0/0!)e^{-\lambda t} + ((\lambda t)^1/1!) \times e^{-\lambda t}$$

$$R = ((1/1) \quad e^{-\lambda t} + ((\lambda t)^1/1) \times e^{-\lambda t}$$

$$R = e^{-0.0001 \times 1000} + (0.0001 \times 1000) \times e^{-0.0001 \times 100}$$

$$R = 0.90484 + (0.1) \times 0.90484 = 0.9953$$

COMPLEX REDUNDANCY
m OUT OF n REDUNDANCY

- Example: At least two of four power supplies in a fire control center must continue to operate for the system to be successful. Let R= 0.9. Find the probability of success.
- SOLUTION:
- $(R + Q)^4 = R^4 + 4 R^3 Q + 6 R^2 Q^2 + 4 R Q^3 + Q^4 = 1$
- For two out of four successes we have:
- $R_S = R^4 + 4 R^3 Q + 6 R^2 Q^2 = 1 - (4 R Q^3 + Q^4)$
- Substituting R = 0.9 and Q = 1- 0.9 = .1 gives:
- $R_S = 1 - (4(0.9)(.1)^3 + (.1)^4) = 1 - (0.0036+0.0001)$
- $R_S = 1 - .0037 = 0.9963$

P SOLVE FOR 3 OUT OF 4

CONCLUSIONS
RELIABILITY BLOCK DIAGRAMS

- RBDs SHOW THE FAILURE LOGIC OF THE SYSTEM WITH BLOCK DIAGRAMS.
- They can be used for most electro-mechanical systems
- RBDs can be used to assist in reliability allocation, to identify critical components of the system, to collect component reliability data and to show how the system responds to a particular failure mode.
- Series, parallel, and complex systems were analyzed.

ADDITIONAL INFORMATION
THE BATHTUB CURVE

OPERATING LIFE TEST EXAMPLE

TEST INVOLVED 7575 PARTS

- **3930 resistors, 1545 capacitors, 915 diodes, 1080 transistors, 105 transformers.**

Components are part of a circuit cards.

- **1/3 tested at -25 °F, 1/3 at 77 °F, 1/3 at 125 °F.**

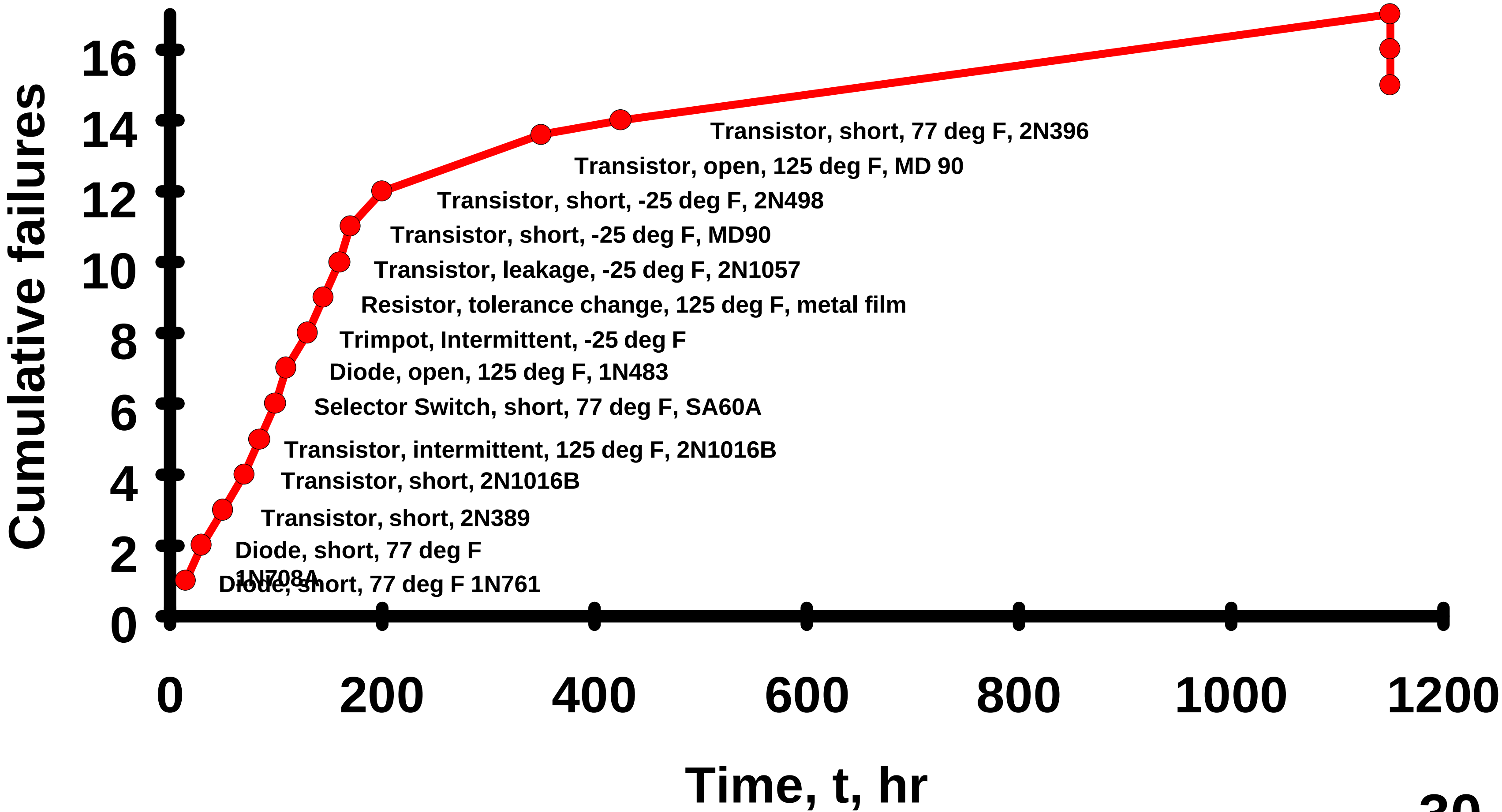
FAILURE RATES -- Constant failure rate

- **CONSTANT FAILURE RATE**
- **The failure rate for the first 1600 hours is constant at one failure every 145 hours.**
- **The failures in the constant rate region are random. The component that fails are generally different from failure to failure.**
- **One component can not be isolated as a major contributor to product performance due to the lack of repetitiveness. The randomness of the failed components precludes any "easy fix" to improve reliability by any significant amount. This is especially true in mature designs.**

EXAMPLE--TEST DATA

(see <u>Reliability</u> <u>Training</u> p. 36 Fig 4-1.)

Observed Parts Failures vs. Test & Storage Time



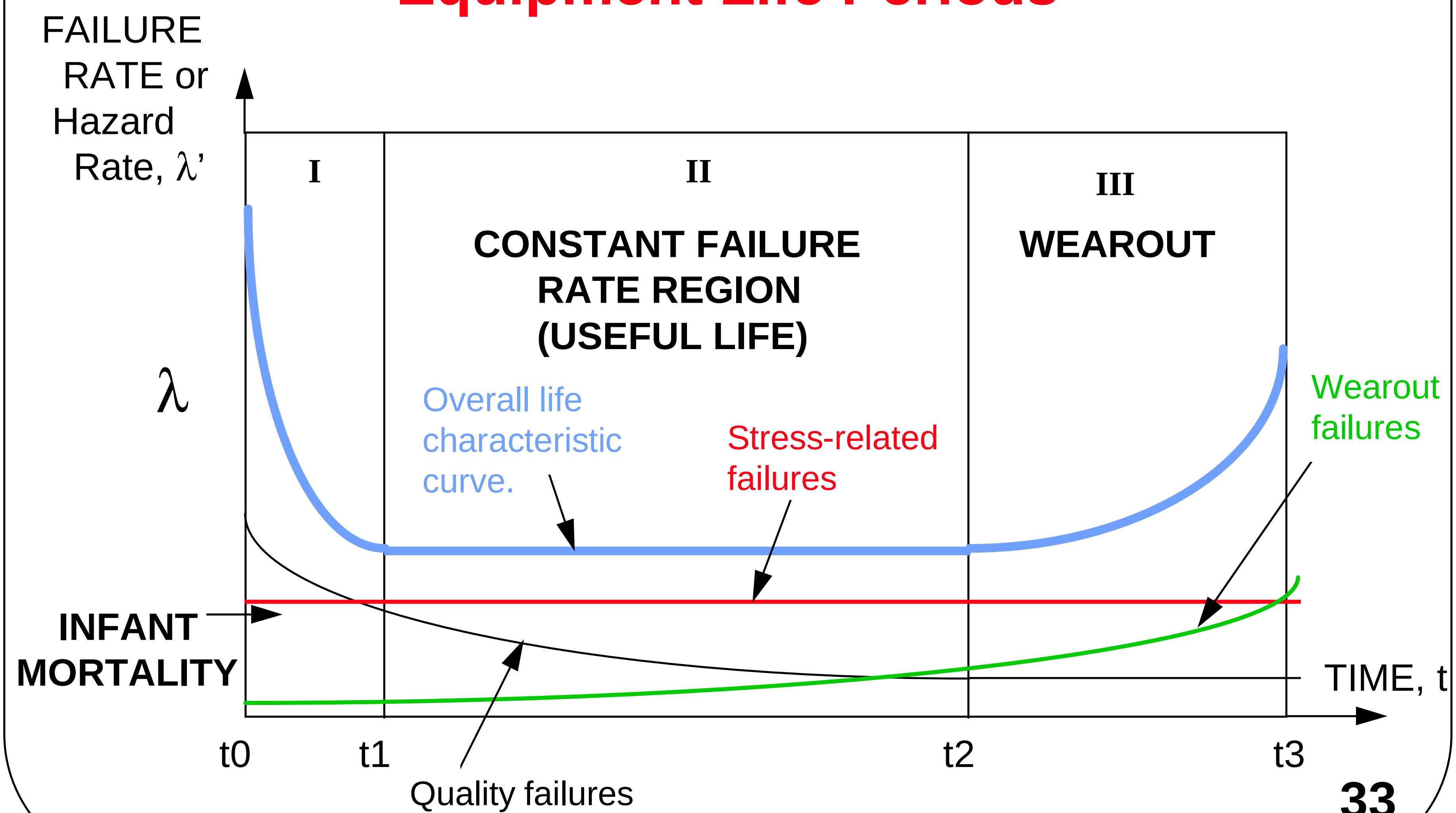
FAILURE MODES--Early Failures

- The short failure mode occurred five times more often than any other failure mode. The transistor failures are evenly distributed among the three environments.
- The diodes failed shorted @77°F & failed open @125°F. One resistor failed intermittent @-25°F & one had a tolerance failure @125°F.

FAILURE MODES Storage Test

- The final portion of the test is a 7000 hr. storage life. At the end of this period there are three failures detected. It is obvious that storage of these components affects their performance since all three failures occurred at start up.

Bathtub Curve
Equipment Life Periods



FAILURE ZONE I -- INFANT MORTALITY

- **Characteristic is an initially high failure rate.**
- **Causes are:**
  - **Poor quality control.**
  - **Insufficient burn-In, break-In.**
  - **Insufficient debugging.**
  - **Poor workmanship.**
  - **Use of substandard components.**
  - **Contamination.**
  - **Improper break-in or start-up.**

FAILURE ZONE II -- USEFUL LIFE

- Characteristic is an “essentially” constant stress failure rate.
- Causes are:
  - Higher than expected loads.
  - Unexplained defects
  - Misapplication and improper usage.
  - Poor design (insufficient safety factor).
  - Chance, random causes.

FAILURE ZONE III -- WEAROUT

- Characteristic is an increasing wearout failure rate.
- Causes is equipment deterioration due to
  - Age
  - Wear
  - Fatigue, Creep, Corrosion
  - Electro-chemical interactions.
  - Use

CONCLUSION
Bathtub Curve

- The bathtub curve illustrates real world failure rates of electronic components.
- The bathtub curve’s three regions are typical for electronic components.
- The flat portion of the bathtub curve is the exponential distribution hazard function.
- Real world test data of electronic components shows constant failure rates under normal operating conditions.

END